Cross Layer Optimization Architecture for Video Streaming in WIMAX Networks

Alaeddine Abdallah, Djamal Eddine Meddour
Orange Labs
2, avenue Pierre Marzin, 22300 Lannion, FRANCE
{alaeddine.abdallah, djamal.meddour} @orange-ftgroup.com

Toufik Ahmed
LABRI, University of Bordeaux 1
351, cours de la libération, 33405 Talence, FRANCE
tad@labri.fr

Raouf Boutaba
Cheriton School of Computer science, University of Waterloo
Waterloo, Canada
rboutaba@uwaterloo.ca

***Abstract*— In this paper, we propose a cross layer optimizer named XLO between scalable video streaming application and IEEE 802.16 MAC layer. The main objective is to allow video streaming application to adapt its parameters according to 802.16 MAC layer conditions and resource availability. XLO uses the existing service flow management messages exchanged between base station (BS) and subscriber station (SS) and makes them available to the video streaming application via a specific XLO interface. We implemented the XLO in the QualNet simulator and performed extensive simulations using a personalized scalable video traffic generator, capable of streaming video with different data rates. We also introduce an enhanced admission control function at the BS that takes into account video adaptability property. The simulation results show the effectiveness of our XLO mechanism for delivering better quality of service.**

Keywords- WIMAX, IEEE 802.16, Video Streaming, Cross Layer Optimization

I. INTRODUCTION

With the prevalence of the Internet today and the diversity of technologies supporting multimedia services, wireless technologies continue to improve in order to provide maximum bandwidth and coverage with the best quality of service and experience for the users.

IEEE 802.16 [1][2], which the WIMAX technology is based upon, is a broadband, high data rate wireless technology. WIMAX technology is intended to support multimedia applications such as real time video streaming. In order to perform efficiently, real time applications require strict resource reservation, namely bandwidth guarantee and bound on the maximum transmission delay, jitter and loss rate. However, the availability of the network resources is subject to network conditions notably at the physical (PHY) and Medium Access Control (MAC) layers. To respond to the lack of resources, video streaming applications should ideally, adapt their data rate according to changes in network conditions observed at the PHY and MAC layers. This process is called awareness and is used in many cross-layer optimisation mechanisms.

Cross-layer design is an ongoing research topic aiming at increasing the Quality of Service/Experience (QoS/QoE) by performing coordinated actions across different network layers and, thus, violating the protocol layered and isolation model.

The contributions described in this paper are two folds. Firstly, we propose a cross layer optimizer, named XLO which facilitates the information exchange between streaming applications and IEEE 802.16 MAC layer to perform rapid video quality adaptations according to physical network conditions. Secondly, we develop a video quality aware admission control function at the BS aiming at guaranteeing the QoS. The objective is to exploit the scalability property of video stream in order to gracefully optimize resource allocation.

The remaining of this paper is organized as follows. Section II presents related works. In section III, we describe our approach. Simulations results are presented in section IV. Finally, section V concludes the paper.

II. BACKGROUND AND RELATED WORKS

A. Related Works

Most previous works on cross layer optimizations in WIMAX networks focus on PHY and MAC layer interactions and do not explicitly consider the application layer (APP) performance. Authors of [3] and [4] propose a Cross layer framework to integrate layer 3 and layer 2 QoS. They introduce a fragment control mechanism which enqueue all fragments coming from different IP packets in the same buffer. They also propose a remapping scheme for better buffer utilization allowing a low frame dropping ratio. In [5], the authors propose a cross layer optimizer between MAC and PHY layer. Their solution collects parameters like channel condition information, bandwidth requests and queue length from both layers and returns optimized parameters back to the two layers.

In [6] and [7], the application layer is included in the cross layer mechanism along with the MAC and PHY layers. Optimization is performed at the BS which delivers video traffic to SS. The authors of [6] utilize information provided by the PHY, MAC and APP layers to improve system performance. The main idea is to adapt and adjust modulation in MAC layer and data rate of the video streaming application depending on channel condition. They introduce new management messages to inform SS about video data rate. In [7], the authors conduct a performance evaluation study of a cross layer approach for multiuser H.264 video transmission in wireless networks. Three steps are defined: abstraction of parameters from the APP and

978-1-4244-7755-5/10/$26.00 ©2010 IEEE

Radio Link layers; selection of optimized parameters and their distribution to corresponding layers. A cross layer algorithm is applied in the beginning of each frame for all users simultaneously which adds a significant overhead.

Our work considers cross layer optimisation between Application and MAC layers at the server side in the SS and not at the BS as in [6] and [7]. Moreover, in our approach, we do not add any new management messages but rather existing MAC management messages. Finally, to reduce computation overhead, our optimization is performed only at the beginning of a video streaming session or during the life-time of a session if changes in MAC layer conditions are detected.

In the next subsection, we discuss QoS support in the IEEE802.16 MAC layer.

B. *QoS design & service flow management in IEEE 802.16*

Each packet passing throw the IEEE 802.16 MAC interface belongs to a service flow (SF) identified by a connection identifier (CID). A SF is a unidirectional flow of packets providing a particular QoS assurance in terms of a set of QoS parameters such as latency, jitter and throughput. A SF may be created, changed or deleted using a MAC management message: DSA, DSC and DSD.

The remaining of this subsection describes these messages which are essential for our cross-layer optimizer.

1) *Dynamic service flow add message (DSA)*

Creation of a SF is initiated by either SS or BS. If SS is the initiator, the message contains reference to concerned SF, QoS parameter sets or service class name. The BS responds by DSA_RSP message indicating the acceptance or rejection of the request. The rejection message may contain extra information such as unsupported parameters or wrong values. When the BS is the initiator, the DSA-REQ message contains SF identifier (SFID), CID and active or admitted QoS parameters. The response of the SS is the same as in the first case.

2) *Dynamic service flow change message (DSC)*

After its creation, a SF can be modified via the DSC-REQ message. The Modification includes admitted and active QoS parameters. Changes are done when both admitted and active parameters are replaced. In fact, if only admitted parameters are included in the message, active parameters will be set to null and SF will be deactivated. When both parameters are inserted in the message, admitted sets are verified first by the admission control mechanism and then the activated sets to ensure that is a subset. If successful, changes take place in the SF; otherwise, the SF become unchanged and continues performing with existing parameters.

3) *Dynamic service flow delete message (DSD)*

A SF is deleted from BS or SS through DSD_REQ message. Moreover, a SF may be deleted implicitly when errors or mistakes occur. The SF management messages will be used in our approach to help XLO fix optimized video streaming parameters and consequently provide better delivered quality of service. Details of our approach are described in the next section.

III. PROPOSED CROSS LAYER OPTIMIZATION APPROACH

A. *Target scenarios & System Architecture*

In this paper, we focus on scenarios where SSs share their video in real time. The appropriate use cases of our approach are video conferencing, video surveillance and P2P video delivery. The main idea of our work consists of optimizing video streaming application initiated by SSs in Uplink channel.

Figure 1 shows a video streaming traffic between 2 SSs associated with different BSs (BS1 and BS2).

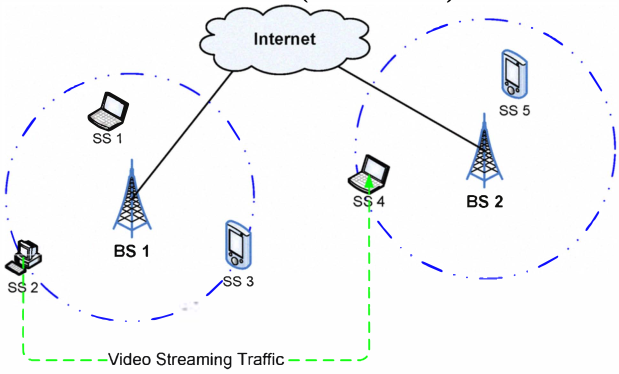

Figure 1. System Architecture

Our approach consists in an adaptation mechanism at the video streaming application jointly with cross layer mechanism between MAC and Application layers. The adaptation occurs at the server side, i.e., the owner of the video content. The protocol stack interactions are illustrated in Figure 2.

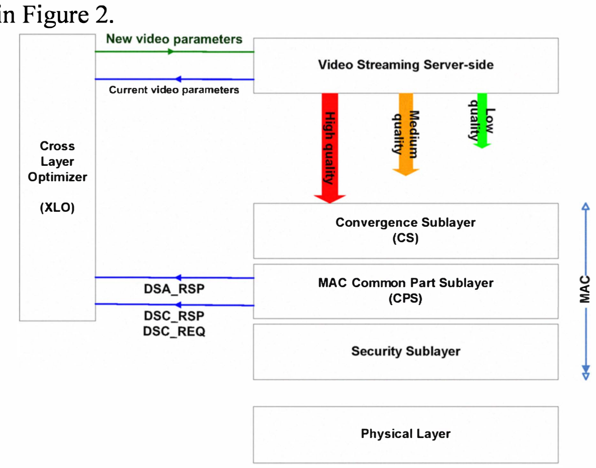

Figure 2. Cross layer optimizer between MAC and application layer

In this figure, we can see the reference model essentially for MAC and PHY layers as defined in IEEE 802.16d standard [1] and the XLO. The XLO makes available the SF management messages (DSA, DSC, and DSD) to video streaming server-side. And this later makes available its video parameters to XLO from the beginning of the streaming session.

The CPS (Common Part Sub layer) provides the core MAC functionality of system access, bandwidth allocation and connection establishment. In particular, CPS is responsible for SF management. Thus, the XLO interacts with CPS sub-layer and video streaming Server-side application layer.

B. *Cross Layer Optimization Algorithm*

The devised cross layer optimization algorithm consists of 3 steps. First, we collect information from CPS sub-layer. Second, this information is analysed and a decision is made at the XLO. Finally, we apply the adaptations by enforcing the new video parameters at the video streaming Server-side.

1) *Collection of information*

As mentioned in section II, SFs are managed (added, changed and deleted) via DSA, DSC and DSD messages respectively. Many messages are exchanged between SS and BS, and we are interested especially in DSA_RSP, DSC_REQ and DSC_RSP messages. The main idea consists in using existing management messages rather than adding new ones. Then, since our approach is implemented in the video streaming server-side, a copy of all SF management messages initiated by the transmitter station or received from the BS will be collected by XLO.

2) *Adaptation & modifications*

The collected SF management messages are first analysed. These messages contain a positive response if the request is accepted and a negative response if the request is not totally accepted or rejected.

If the request is not accepted, it indicates the unavailability of the needed resources for the video stream. Hence, the video streaming application has to adjust its behaviour in order to get a positive response in the next attempt. For this end, we modify the streaming parameters so as to adjust the video data rate throughput. This procedure may be repeated until the video stream is accepted or we reach the minimum video quality supported with a reject response. The selection of the minimum and maximum video quality as usually negotiated using existing signalling protocols such as SIP or H323 can be part of the service level agreement. This is however out of the scope of this paper.

Once the request is accepted, the information and the time of acceptance are stored. Then, if the video stream performs correctly for a certain period, the XLO will increase the video data rate assuming that more resources are available. If the request is rejected, the video stream will continue using its current parameters. If accepted, the same process is repeated until we reach the maximum video quality. An algorithm describing this process is given below.

Algorithm 1 *XLO Algorithm*

```
1 :  Wait for SF management message or Time Out to increase
2 :  If  SF management message then
3 :      if  Success  then
4 :          //no Optimization needed
5 :          Start Time Out to Increase
6 :      else if  Reject  then
7 :          if  minimum video quality not reached then
8 :              Change Video streaming parameters
                      (decrease data rate)
9 :              go to 1:
10 :         end if
11 :     end if
12 : end if

13 : if Time Out to Increase  then
14 :     if  maximum video quality not reached  then
15 :         Change Video streaming parameters
                  (increase data rate)
16 :         go to 1:
17 :     end if
18 : end if
```

The next subsection presents the sequence diagrams that provide more details about the cross layer optimization operations and the exchanged messages between the entities involved in the optimization process.

C. *Illustration of the approach*

If a new video is requested, the XLO allows us to identify the suitable video parameters that guarantee the acceptance of the corresponding SF at the MAC layer. During the video streaming, the changes occurring in the MAC layer conditions and consequently in the video throughput may force the service to be stopped or rejected. In the absence of our XLO, the video stream will abort if the SF parameters do not meet its QoS constraints. The XLO allows us to adapt video streaming data rate according to the fluctuation of the network conditions and hence avoids the SF rejection. Furthermore, our approach can be applied at the service request / invocation as well as during the life-time of the session or at service delivery.

In the following, we will illustrate our approach through some examples. We use the topology presented in Figure 1, where in the SS2 station we implement a video streaming server with XLO capability.

1) *SS initiated DSA request message*

If the MAC layer in SS2 receives a video, it initiates a DSA_REQ message with the desired QoS parameters and sends it to the BS1, which checks the integrity of the message and responds by DSX_RVD (DSA or DSC received) message. Then, depending on the acceptance or rejection of the QoS parameters, BS1 sends DSA_RSP message with a success or reject code.

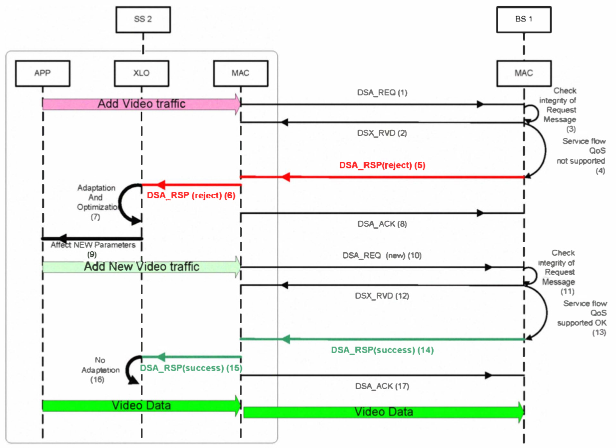

Figure 3. SS initiated DSA Request Message

In Figure 3, we present the sequence diagram where a new SF is rejected in the first attempt and accepted in the second attempt thanks to XLO. In fact, once the SS receives a DSA_RSP reject message (step 5), it forwards it to XLO (step 6). The latter intercepts the message and commands the video streaming application to adapt its QoS parameters by reducing its video data rate (step 7 and 8). Then, a new video add request is initiated. The same procedure between BS1 and SS2 is performed. The request is accepted and the video streaming started.

After the acceptance of a new video flow, the channel conditions and availability of resources might vary. In this case, BS or SS should send a DSC request message in order to change service flow QoS parameters.

2) BS initiated DSC request message

The sequence diagram depicted in Figure 4 shows a BS initiating a DSC request message (step 2). In fact, a BS should send a DSC request message once it is unable to meet the new SF QoS constraints. This might happen in two cases, when the required resources at the BS side are unavailable, and when the QoS constraints cannot be satisfied by the link between BS1 and the receiver station SS4, BS1 send a DSC request message to SS2 in order to adapt the SF parameters accordingly. Then, SS2 receives the request and changes SF parameters consequently (step 3).

3) SS initiated DSC request messag

An SS must initiate a DSC_REQ message if it detects changes in the channel conditions. In this case, it requests BS1 to change corresponding SF QoS parameters by increasing or decreasing the related video data rate. Once the BS1 receives DSC_REQ message, it replies by DSX_RVD message if the request message is valid (step 4 in Figure 5). Then, it checks if the new SF parameters can be supported and sends DSC_RSP message to SS1 with a reject or success response.

If the request is rejected, SS1 will continue with its current parameters. If the request is accepted as mentioned in step 6, it sets up new SF parameters. Therefore, the XLO avoids the rejection of new video SF by adapting the video streaming parameters accordingly (step 8 and 10).

IV. SIMULATION ENVIRONMENT AND RESULTS

A. *Simulation environment*

We consider the same topology in Figure 1, the link between BS1 and BS2 is assumed to be a reliable wired link since we focus essentially on WIMAX networks performance. We use QualNet Network Simulator [9] which implements PMP (point to multipoint) mode of IEEE802.16, and in which we implemented our XLO. We set IEEE 802.16 PHY parameters as mentioned in TABLE I.

We simulate a video streaming traffic from SS2 to SS4 with different scenarios using video traffic generator based on pre-encoded MPEG4 traces [8]. These traces provide three video qualities: high, medium and low video quality, see TABLE II. for more details. We developed a new scalable video streaming generator based on MPEG traces which is capable of varying video quality and consequently varying video data rate.

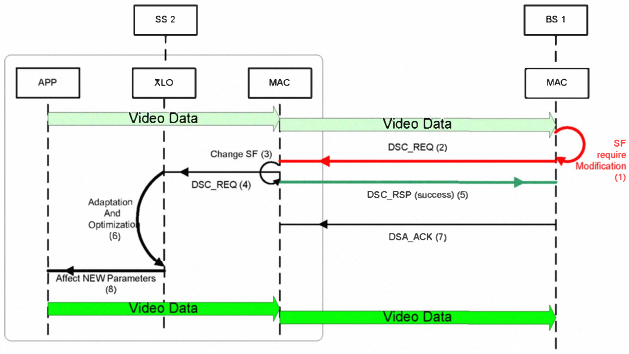

Figure 4. BS initiated DSC Request Message

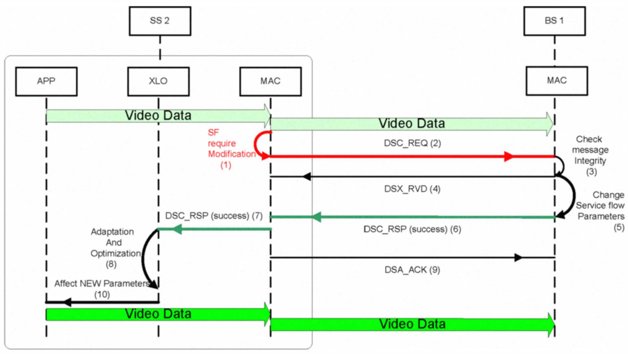

Figure 5. SS initiated DSC Request Message

TABLE I. IEEE 802.16 PHY SIMULATION PARAMETERS

Propagation channel frequency	2.4 GHz
Channel bandwidth	20 MHz
FFT size	2048
Antenna gain	12 dB
Transmission Power	20 dB
Frame size	20 ms

TABLE II. HIGH, MEDIUM AND LOW VIDEO QUALITY

	Video quality		
	High	***Medium***	***Low***
Frame rate	25 frames / sec	25 frames / sec	25 frames / sec
Mean data rate	766 Kbps	267 Kbps	153 Kbps

In the next subsection, we describe four simulated case scenarios and discuss the simulation results.

B. *Simulation results*

1) Scenario 1:Normal conditions

This first scenario evaluates the throughput of video streaming under normal condition, and assuming there are enough resources in the network. Figure 6 shows the simulation results for high, medium and low video quality. The obtained bit rate for each quality is indicated in the Y axis. These curves will serve as a baseline for better understanding the subsequent scenarios.

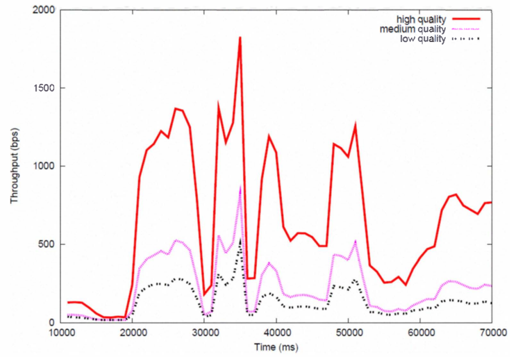

Figure 6. High, medium and low video quality data rate

2) Scenario 2: admission control adaptation

In this scenario, we evaluate the performance of the proposed solution in the presence of an admission control mechanism. In addition to our scalable video streaming traffic from SS2 to SS4, we add background traffic from SS1 and SS3 to SS5 with higher priority to disrupt video traffic. We choose real time CBR traffic with a high bit rate so that BS1 will not have enough resources to satisfy high video quality and force the video streaming server to reduce its data rate until satisfaction as explained in Figure 3.

Background traffic runs during all simulation time, and video streaming traffic starts at t = 10sec for one minute long. TABLE III indicate background traffic data rate in each scenario. By default, the video streaming server starts transmitting with high video quality and keeps XLO adapting its data rate according to BS feedbacks.

In Figure 7, we can observe how the application switches immediately from high to medium quality with only few packets belonging to high video quality, and then the curve takes the shape corresponding to the medium quality. The same behavior is observed in Figure 8 where XLO moves the video quality down to a low level. In fact, CBR traffic data rate is high enough (30.75 Mbps) that BS1 has no longer available resources to satisfy high or medium quality.

TABLE III. SCENARIOS BACKGROUND TRAFFIC SETTINGS SETTINGS

	Description	***Background CBR traffic data rate***	***Related figures***
Scenario 2	High reduced to medium quality in admission control	30.6 Mbps	Figure 7
	High reduced to low quality in admission control	30.75 Mbps	Figure 8
Scenario 3	High reduced to medium quality during lifetime streaming	30.6 Mbps	Figure 10
	High reduced to low quality during lifetime streaming	31 Mbps	Figure 11
Scenario 4	Low increased to High video quality during lifetime streaming	30.75 Mbps Ends at 40sec	Figure 12

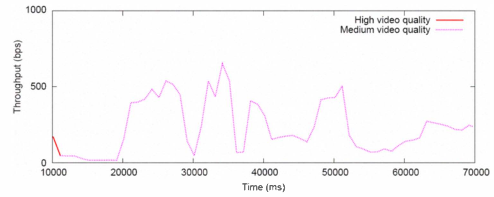

Figure 7. High reduced to Medium quality video data rate in admission

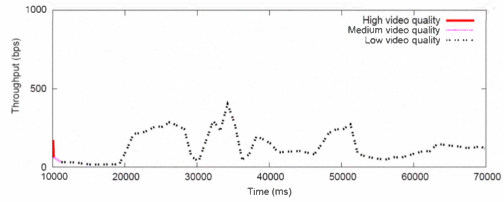

Figure 8. reduced to Low quality video data rate in admission

3) Scenario 3: adaptation during video streaming (decrease video data rate)

This scenario aims to show how XLO works during the life-time of the video streaming session; we simulate the same configuration of the precedent scenario. CBR data rate is chosen so as to give high video quality the chance to be accepted from the beginning of the streaming session.

Then, at t = 30sec, we initiate another CBR traffic with higher priority. We manage its data rate so that BS will not have enough resources for already existing video traffic. The total data rate of background traffic is mentioned in TABLE III. We run this scenario without XLO, and we obtain the results given by Figure 9. We can see that with no XLO, when BS cannot satisfy the high quality video data rate, a reject message is sent to SS2, the SF connection aborts and the video streaming traffic is simply interrupted while, with XLO, the results are different. In fact, thanks to our optimization in its scheduling algorithm, BS is aware of SFs related to scalable video streaming application. Consequently, as shown in Figure 4, XLO will force the video streaming server-side application to adapt and reduce its data rate. Figure 10 shows the simulation results for a scenario where video data rate is reduced to the data rate of the medium video quality. Figure 11 shows simulation results for a scenario where video data rate is reduced multiple times until it reaches a low video quality.

4) Scenario 4: adaptation during video streaming (increase video data rate)

In this scenario, we reuse the same simulation settings as in scenario 2 with a background traffic of 30.75 Mbps starting in the beginning of the simulation but ends at t = 40sec and not during all simulation time. As mentioned above, video data rate will decrease, thinks to XLO admission control, until reach low video quality. Then, at t = 40 sec, background traffic stopped and the resources it used become available. When the XLO entity detects this availability, it informs the video streaming server in order to increase its video data rate. A first DSC request message is sent from SS to BS to reach medium video quality as mentioned in Figure 12, and then a second DSC request is sent to reach high video quality.

V. CONCLUSION

In this paper, we introduced a cross layer solution for adaptive video streaming applications in IEEE 802.16 networks. The XLO collects information provided by the MAC layer, essentially SF management messages exchanged between BS and SS and assigns new optimised parameters to video streaming server-side application. The ultimate goal is to adapt video data rate according to resource availability at the MAC layer. The conducted simulations showed that adaptation can be performed during the admission control and the life-time of video streaming sessions and allows a continuous video stream with no interruption especially if there are no available resources for the high video quality. Our future work includes the extension of the current optimizer to multi hop relay WIMAX networks. Moreover, the cross layer optimization described in this paper follows a bottom-up approach where application benefits from lower layer parameters. It will be interesting to complement it with a top-down approach to make the MAC layer adaptable according to video application needs.

ACKNOWLEDGMENT

This work was funded by the Information Society Technologies program of the European Commission, SMART-antenna multimode wireless mesh Network under the ICT-2-1.6 SMARTnet Project.

REFERENCES

[1] IEEE Std 802.16, "IEEE Standard for Local and metropolitan area networks. Part 16: Air Interface for Fixed Broadband Wireless Access Systems", October 2004.

[2] IEEE Std 802.16e, "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems. Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands and Corrigendum 1", February 2006.

[3] Yi-Ting Mai; Chun-Chuan Yang; Yu-Hsuan Lin, "Cross-Layer QoS Framework in the IEEE 802.16 Network," Advanced Communication Technology, The 9th International Conference on , vol.3, no., pp.2090-2095, 12-14 Feb. 2007

[4] Y. T. Mai, C. C. Yang, and Y. H. Lin, "Design of the Cross-Layer QoS Framework for the IEEE 802.16 PMP Networks," IEICE Transactions on Communications, vol. E91-B, no. 5, pp. 1360-1369, May 2008.

[5] Noordin, K.A.; Markarian, G., "Cross-Layer Optimization Architecture for WiMAX Systems," Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007. IEEE 18th International Symposium on , vol., no., pp.1-4, 3-7 Sept. 2007

[6] D.-K. Triantafyllopoulou, N. Passas, and A. Kaloxylos, "A Cross-Layer Optimization Mechanism for Multimedia Traffic over IEEE 802.16 Networks", European Wireless 2007, Paris, France, Apr. 2007.

[7] Fan Li, G. Liu, L. He, "Application-driven cross-layer design of multiuser H.264 video transmission over wireless networks", Proceedings of the 2009 International Conference on Wireless Communications and Mobile Computing: Connecting the World Wirelessly, pp. 176-180, 21-24 Juin 2009.

[8] MPEG-4 and H.263 Video Traces for Network Performance Evaluation.[Online].Available:http://www.tkn.tu-berlin.de/research/trace/trace.html

[9] Scalable Network Technologies (SNT). QualNet. .[Online]. Available: http://www.qualnet.com/

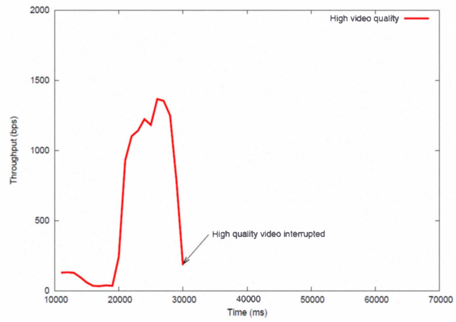

Figure 9. High quality video data rate interrupted during transmission

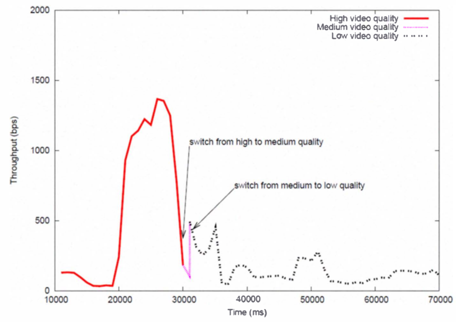

Figure 11. High reduced to Low quality video data rate during transmission

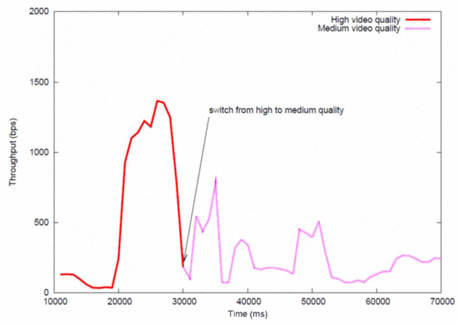

Figure 10. High reduced to Medium quality video data rate during transmission

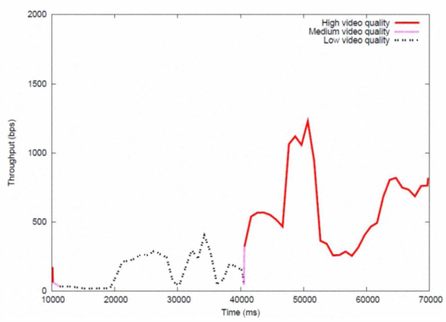

Figure 12. Low increased to High quality video data rate during transmission